OTS: 60-11,919

JPRS: 5025

18 July 1960

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- USSR -

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Distributed by:

OFFICE OF TECHNICAL SERVICES
U. S. DEPARTMENT OF COMMERCE
WASHINGTON 25, D. C.

U. S. JOINT PUBLICATIONS RESEARCH SERVICE
205 EAST 42nd STREET, SUITE 300
NEW YORK 17, N. Y.

JPRS: 5025

CSO: 3881-N

ATMOSPHERIC AIR POLLUTION WITH RADIOACTIVE SUBSTANCES

/Following is a translation of an article by Prof. V. F. Oreshko and Candidate of Medical Sciences Yu. V. Novikov in Gigiyena i Sanitariya (Hygiene and Sanitation), Vol. 25, No. 2, Moscow, 1960, pages 64-70./

From the Moscow Scientific Research Institute of Sanitation and Hygiene imeni F. F. Erisman of the Ministry of Health RSFSR.

Testing of atomic and hydrogen weapons inevitably leads to pollution of the air of the entire terrestrial globe with radioactive substances.

In an air explosion of an average atom bomb, the nuclides reach the upper atmospheric portion of the troposphere -- the tropopause. Since all weather phenomena, for example, wind, storm, cloud formation, rain, etc., take place in the troposphere, the fall-out of nuclides from the troposphere into the surface atmospheric layers occur much faster than during their penetration into the stratosphere where these phenomena are absent.

Under the effect of the immense force of a nuclear bomb of great power and a large amount of discharge of thermal energy, a considerable part of the radioactive cloud passes through the tropopause and rises to the stratosphere to a height of 30,000 meters. Comparatively large particles return to the troposphere, while small particles of one micron or less remain in the stratosphere for a long time, 10 years on the average. Therefore, the part of fission products which passes into the stratosphere settles on the ground at a very slow rate. Since the process of diffusion and mixing in this instance takes a long time, the precipitation of radioactive dust occurs evenly and with an almost uniform speed over the entire surface of the earth. These precipitates consist exclusively of long-life fission products and differ in this respect from local precipitates, a considerable part of which represents fission products with small periods of half-life.

The basic part of the radioactive dust is precipi-

tated with the rain water, and, on the average, half of the fine dust formed after an explosion of a small bomb is precipitated by rains within 22 days; but in the explosion of thermonuclear bombs with the equivalent of several million tons of trinitrotoluol, whose cloud reaches a height of 30,000 meters, the radioactive dust is retained in the air for several years, and during a year, 10 to 20 percent of the dust formed precipitates. The character of local precipitation of the radioactive dust depends on a number of factors of which the important ones are: the distribution of particles in the explosion cloud according to their size, and the metereological conditions. The most important metereological factors are the direction and force of the prevalent winds.

According to the Japanese data, particles of dust larger than 0.1 mm which had formed during the Bikini explosion on 1 March 1954 spread at a distance of 225 km with the wind, and 65 km against the wind. The finer dust with particles of 0.05 mm size spread with the wind to a distance of 1000 km. The dust precipitation following a thermonuclear explosion may occur at longer distances -- over 9600 km (remote precipitations), and its distribution over the earth's surface is determined by the total wind of an air-layer within the altitude limits of 1,000 to 30,000 m. (1)

Cronkite, et al describe the damaging effect of radioactive dust which fell out after the explosion of 1 March 1954 in the region of Marshall Islands. Twenty-eight American service men and 239 inhabitants of the islands were subjected to the effect of radioactive dust. The irradiation doses which they received were within the limits of 15 to 175 r. Of Marshall Islands residents, 64 received an irradiation dose equal to 175r. No fatal cases were observed; however, within two weeks following irradiation in 90 percent of the injured individuals, affections of the skin and the falling out of hair were observed.

The radioactive dust precipitation from the atmosphere as a result of natural sedimentation processes, as well as with rains, snow, etc., leads to the accumulation of radioactive substances on the surface of the earth. The intensity of soil contamination with fission products, with radioactive elements in particular, not found among the

(1) The wind direction in the stratosphere is predominantly to the east and west; in the so-called stream currents the wind velocity reaches 320 km per hour.

natural radioactive elements of the terrestrial core, for example Sr^{90}, can be used to indicate the degree of air pollution and the intensity of precipitation of radioactive products of atomic explosions.

The study of Sr^{90} accumulation on the earth's surface presents the more interest because, with its long half-life [29.3±1.6 years (M. P. Anikina, et al.)7, it accumulates in the bone tissues and exerts an injurious effect on the human organism even in comparatively small concentrations. The emission of Sr^{90} in fission reaction represents, according to the data of K. K. Aglintsev, etc., 5.8 percent, and its percentage content in the fission products increases rapidly due to its long half-life.

Eisenbud and Harley cite the data of contamination of the earth surface with Sr^{90} and the doses of gamma-radiation from the total of fission products, in proportion to the general quantity of these products which had been precipitated up to 1 January 1956 in various regions of the terrestrial globe. The highest figures of accumulation of the total fission products, the contamination of the earth's surface with Sr^{90}, and the doses of gamma-radiation from the total fission production are noted in the firing test grounds in Nevada and the Pacific Ocean. In Salt Lake City (the state of Utah, USA) the total precipitation of fission products reaches 680 microcuries/mi^2(*), Sr^{90} represents 23 mc/mi^2, and the gamma-radiation dose from fission products -- 160 mrad. High figures of these indicators (740 mC/mi^2, 18 mC/mi^2, 120 mrad) were noted in the city of Grand Junction (Colorado, USA). Correspondingly high figures of 290 mC/mi^2, 24 mC/mi^2 and 15 mrad are observed in the western part of the Pacific (Iwo Jima). A minimum accumulation of fission products, Sr^{90}, and of gamma-radiation doses are noted in the city of Lagos, Nigeria -- 33 mC/mi^2, 1.9 mC/mi^2 and 46 mrad, respectively. In the majority of regions of the earth's surface the fallout of a total amount of fission products is characterized by a high degree of zonal uniformity. The regions of the terrestrial globe where these figures fluctuate as much as ± 50 percent are an exception.

Upon comparing the data of accumulation of fission fragments on 1 January 1956 with the data of the same authors for 1 January 1955 for the United States, one can note that the index figures increased several times for 1 January 1956. While the maximum accumulation of fission products in certain regions was equal on 1 January 1956 to 740 mC/mi^2,

* mi^2 means a square mile

on 1 January 1955 it was 120 mC/mi^2. The minimum figures were, correspondingly, 47 and 33 mC/mi^2, and in the majority of cases the accumulation of fission fragments for 1 January 1956 is expressed in hundred mC/mi^2, while for 1 January 1955 it is expressed in tens mC/mi^2.

The Sr^{90} precipitation from the atmosphere and its accumulation on the surface of the earth vary considerably depending on various meterological factors.

From the average Sr^{90} concentration figures of two to five mC/mi^2 in various regions of the earth's surface, the intensity of Sr^{90} precipitation may change several fold.

According to the journal "Science," the dynamics of the contamination of earth's surface with Sr^{90} is as follows: in 1953-54 the Sr^{90} contamination constituted five mC/mi^2, in 1954-55 nine mC/mi^2, in 1955-56 - 18 mC/mi^2, and in 1956-57 -- 28 mC/mi^2.

According to the report of the Atomic Energy Commission of the United States, during the year 1957 only, the amount of precipitation of radioactive strontium increased by 50 percent. In the beginning of 1957 the general level of Sr^{90} contamination constituted in the New York area 11.2 mC/km^2. In December 1957 the total quantity of precipitated Sr^{90} in this area constituted 17 mC/km^2.

The determination of the average daily density of the fall-out of radioactive precipitates conducted by V. P. Shvedov and associates from 1954 to 1958 also confirms the continuous increase of activity. In 1954 the average daily activity of fall-out precipitates constituted 0.73 mC/km^2, in 1955 -- 1.28 mC/km^2, in 1956 -- 0.7 mC/km^2 and in 1958 -- 1.67 mC/km^2. On certain days the maximum activity for 24 hours reached 12-93 mC/km^2. Studies conducted in Chilton and Milford-Haven (Great Britain) from February 1951 to December 1956 show that the activity of the fall-out precipitates varies within large limits; however very high activities are observed comparatively rarely (see Table).

The highest daily activity, equal to 190 mC/mi^2 in Chilton and 240 mC/mi^2 in Milford Haven, was observed during a heavy rain five days after atomic tests in Nevada in the autumn of 1951. The greatest activity of precipitates for 24 hours following an explosion of a thermonuclear bomb consituted in Chilton 25 mC/mi^2 and in Milford Haven 100 mC/mi^2.

The intensity of radioactive dust fall-out in the Leningrad area, according to the data by N. M. Tomson, who had studied it for seven months, fluctuated between 0.04 to $26.3 \cdot 10^{-9}$ mC/mi^2 at an average activity of $1.9 \cdot 10^{-9}$ mC/mi^2. The maximum activity was observed in

September. The radioactivity of the snow layer, characterized by the intensity of radioactive dust precipitation, according to the data of V. Z. Yas'kova in Leningrad fluctuated during a three-month period between $0.3 \cdot 10^{-9}$ to $10.2 \cdot 10^{-9}$ mC/mi^2.

Daily precipitations of radioactive substances observed in Chilton and Milford Haven between Feb. 1951 and Dec. 1956.

Range of activity rate of precipitates (mC/mi^2)	Frequency of groups	
	Chilton	Milford Haven
5-25	83	76
26-50	9	5
51-100	3	1
101-150	3	-
151-200	1	-
201-250	-	1

In certain regions of the earth the level of radioactive contaminations may reach comparatively small figures as compared to the natural level of radioactivity of the atmospheric air.

According to the data of Japanese authors, the Sr^{90} concentration in the atmospheric air was at the level of $0.29 -- 1.06 \cdot 10^{-17}$ C/L.

The atmospheric content of Sr^{90} at the approximate altitude of 7000 meters constituted on the average $1.8 \cdot 10^{-17}$ C/L, with fluctuations from 0.26 to $7.8 \cdot 10^{-17}$ C/L. At the altitude of 5000 m the average concentration of Sr^{90} was at the level of $1 \cdot 10^{-17}$ C/L, i. e., less than at the 7000 m altitude. The Sr^{90} concentration at the ground air layers was noticeably lower than at high altitudes -- from $0.063 \cdot 10^{-17}$ C/L. The average annual rate of Sr^{90} fall-out in 1957 was at the level of 2.8 mC/km^2 per year (B.V. Kurchatov, etc.).

Studies of radioactive dust concentration in the ground layers of air, conducted in Harwell (Great Britain) since 1951 for a period of seven years, showed that the average level of radioactivity from nuclear explosions in Great Britain constituted about one percent of the natural radioactivity level.

The problem of local contamination of the atmospheric

air is important to hygienists.

Thus, according to the data in foreign literature, the Brookhaven uranium-graphite reactor where atmospheric air is used as a cooler, expels through the exhaust tube into the atmosphere during its normal operation, 7,000 C A^{41} per day. When the fuel element is damaged, xenon and other gaseous fission products are detected in the expelled air (M. Fox).

In various kinds of damage and breakdowns of the reactors, a massive ejection of radioactive substances into the atmospheric air may occur. Thus, for example, during the breakdown of a reactor in a plutonium plant in Windscale on 10 October 1957, 20,000 C J^{131}, 600 C Cs^{137}, 80 C Sr^{89} and 9 C Sr^{90} were ejected. Apparently J^{131} and Cs^{137} predominated in the ejected material. This reactor was air-cooled.

For a retarder graphite was used; the fuel was natural uranium. The cooled air was propelled through the reactor by means of powerful gas blowers and was expelled into the atmosphere through an exhaust tube 122 meters high, provided with a filter at its upper part.

Following the ejection, a thorough testing of air radioactivity was done in the entire area. A total of 12,000 samples were taken in the explosion area and 1,000 samples were taken in the adjacent area. Samples from the explosion area showed considerable fluctuations in the radioactivity levels. During the night of 10 October 1957, the level of beta-activity of the air was of the $2.3 \cdot 10^{-11}$ C/L order with a maximum up to $0.5 \cdot 10^{-9}$ C/L. The average level of air contamination was $0.5 \cdot 10^{-11}$ C/L which exceeds twofold the liminally permissible air contamination level of working premises, according to the recommendations of the International Commission for Protection from Radioactive Radiation. The highest figure determined in the adjacent area during the night of 10 October was $2.7 \cdot 10^{-11}$ C/L at a distance of about 3.2 km from the plant. Generally, the contamination levels were lower. Twelve hours later, on 11 October the contamination levels in the explosion area and beyond decreased rapidly (Dunster, Howells, and Templeton).

The air contamination with radioactive iodine did not represent a direct danger to the population; however, the radioactivity of the milk of the cattle fed on the grass on which radioactive iodine had precipitated reached dangerous proportions. For this reason, the milk from farms situated around Windscale for an area of 500 km^2 had to be poured into the sea through the drainage system for a certain period of time.

At a Hanford plant, where U^{238} and Pu^{239} are separated, the following radioactive elements are ejected into the atmospheric air: iodine, strontium, yttrium, niobium, ruthenium, desium, and cerium. The operations of block diffusion are temporarily stopped during unfavorable meteorological conditions because excessive precipitation of these elements may threaten the health of the population. As a result of determination of the radioactivity of vegetation growing around the production area, it was found necessary to erect in Hanford a special installation to purify the waste material, in order to extract, as much as possible, the radioactive substances prior to their absorption by the air and subsequent ejection into the atmosphere through the exhaustion tube.

The danger of contamination of the air and of the adjacent localities, especially after a breakdown in local atomic enterprises, is now taken into account in planning and allocating new construction of atomic plants and power stations.

In planning the 180,000 kv Dresden atomic power station an area of 385 hectares was set aside in the northern part of the state of Illinois (USA). The area and the water cooling system meet the requirements for a regular power station of over one million kv. It is situated in an agricultural region at 22 km distance southwest of Joliet, the nearest large center with a population of 50,000, and 80 km southwest of Chicago with a population of 3.7 million.

The New York atomic power station of 140,000 kv will occupy an area of approximately 140 hectares situated 40 km north of New York on the eastern shore of the Hudson. This section is poorly populated, as compared to the high density of the Greater New York area as a whole. There are no residential buildings or industrial enterprises in a 400 m radius, only 16 one-family houses in a 800 m radius, and no industrial enterprises. There are only about 45,000 people living within eight km.

The atomic power station "Enrico Fermi", of 156,000 kv power, will be constructed on an area of 370 hectares, within approximately 50 km southwest of Detroit, in Laguna Big (Michigan state) on the western shore of Lake Erie. Twelve km north from this area is the city of Monroe, population 20,000, and within eight km radius are four resort villages with a permanent population of less than 2,000 which is approximately doubled during the summer vacation period. The population in the vicinity is distributed as follows: at a radius of 1, 6, 8, 16, and 32 km there are 175, 1,800, 31,300, and 187,000 residents, respectively.

To protect the population from radioactive gases and aerosols, their waste is usually disposed of through a high exhaust tube so as to reduce the radioactivity concentration by diluting with air.

The dilution of radioactive gases is intensified by blasting pure air into the chimney by means of ventilators, as well as through artificially heating the gases to reduce their density. The latter, so to speak, increases the height of the exhaust tube. However, the dilution of radioactive substances by means of ejection of gases through the exhaust tube does not remove the possibility of slow accumulation of radioactivity in the surrounding area which results from the precipitation of the particles. The heat inversion, descending currents, and certain wind directions may, under certain conditions, cause precipitation of large quantities of these particles even in artificially diluted activity. High chimneys serve only to pulverize radioactivity, but do not eliminate or reduce it.

The method of dilution of radioactivity is most effective with short-life substances. Here the problem consists only in maintaining a low concentration until the complete disintegration takes place. It is thought that expulsion of radioactive gases through the smoke chimney considerably reduces concentration. But by this route the radioactivity may be concentrated by vegetation which absorb radioactive substances well.

The height of expulsion fluctuates between the limits of 30 to 150 meters, depending on a concrete case; in British atomic installations it usually reaches 100 meters.

Parker notes four factors which affect the distribution of radioactive substances in the vicinity of a plant which processes high-activity elements: the rate of waste removal, the height of the chimney, metereological conditions, and the topography of the locality. The height of the chimney is of importance only in the zone immediately adjacent to the plant. In this zone the figure of maximum concentration of contaminated material on the earth's surface is approximately in inverse proportion to the square root of the height of the chimney. In instances of average chimney heights of 60 to 100 meters, the contaminations will be very insignificant at distances exceeding five km from the base of the chimney. The metereological factors are divided by the author approximately into three groups, depending on the gradient of temperature, height, and velocity of air movement.

The character of radioactive waste expulsion determines the use of various purifying devices. In the United States three types of liquid scrubbers are used to collect radio-

active dust (A. S. Brelove). In the Piz-Antoni scrubber, water drops are employed in collecting hard dust particles. Scrubbers of this type are unsuitable for collecting dust particles of less than one micron due to the property of small particles to flow over the water drops together with the air current. Such scrubbers are not used independently but as a basic part of a complex air-purifying installation. In the Venturi scrubber, gas passes with great velocity through the vent and pulverizes water. As the result of whirlpools formed in the vent, gas is mixed with the water spray, thus increasing the number of probable collisions of dust particles with the drops of water. Then, the water spray is precipitated in a cyclone /dust extractor/. The effectiveness of this device about 90 to 98 percent. In the Peabody scrubber with perforated plates and mounted vapor injectors the effectivness reaches 99.99 percent. The cyclones are employed as preliminary filters (Brelove).

The highly effective asbestos-cellulose filter has found wide distribution in the United States. Of other filtering substances, mineral filters can be mentioned: the glass cotton of 1.5 and 0.5 micron fiber thickness and the Bolivian blue asbestos. Of the heat-resistant filters, fibra-flax consists of 50 percent Al_2O_3 and 50 percent SiO_2. Of this material a filter was made which can withstand a 1000° temperature.

All these purifying devices require deactivation of precipitates accumulated in them for which a distance removal of accumulated radioactivities is arranged with a corresponding protection of the personnel.

Thus, the problem of air contamination with radioactive substances acquires at present a constantly increasing importance. In this connection, hygienists, physicists, and radiochemists face important tasks of discovering the rules of the diffusion of radioactive substances in the atmosphere, the study of the degree of toxicity of radioactive contaminations to the population, and the development of preventive measures of combatting these contaminations.

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